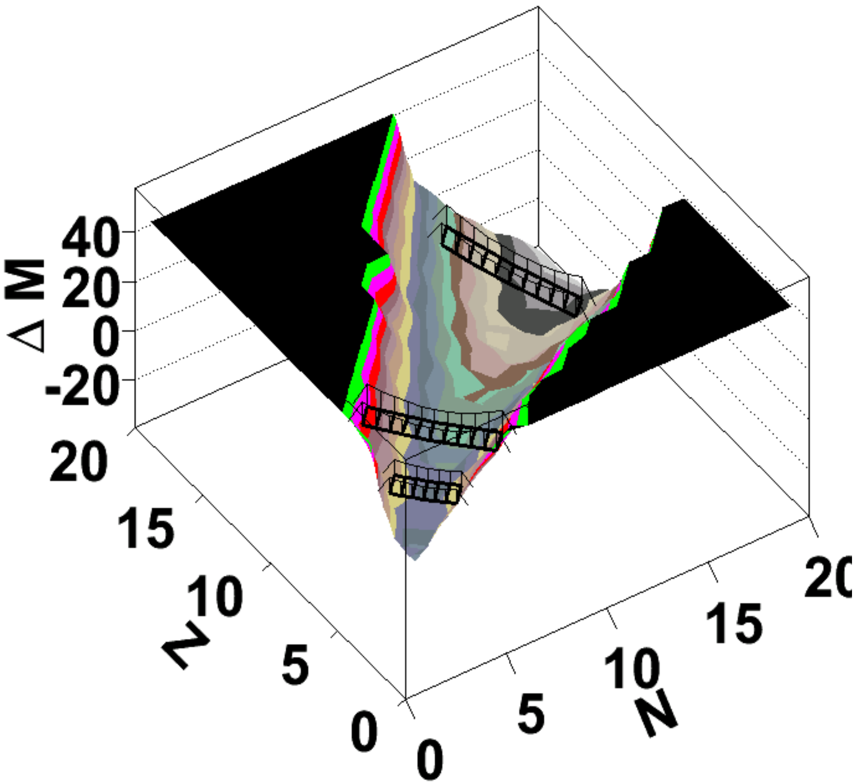

Two and Four Proton Decays in ^{8}C and ^{12}O Ground States and Their Isobaric Analog

NS2012

Using two-proton decay to build isospin bridges across the valley of stability

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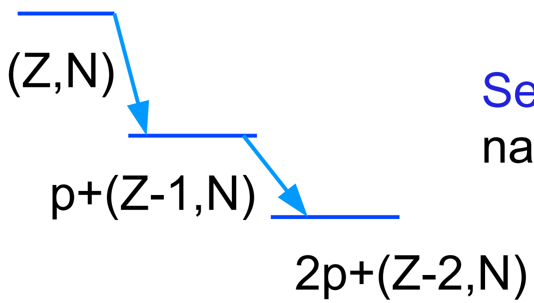
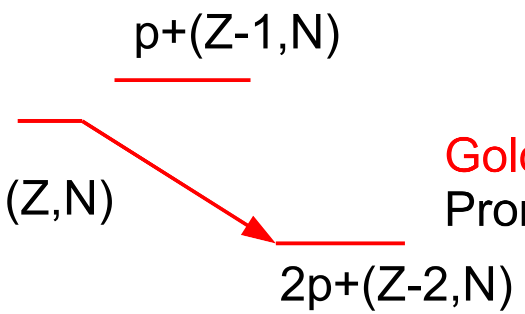
Howard, Rutgers Univ.

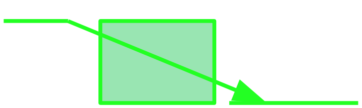
Types of two-proton decay



Sequential,
narrow intermediate state $^{10}C^*$

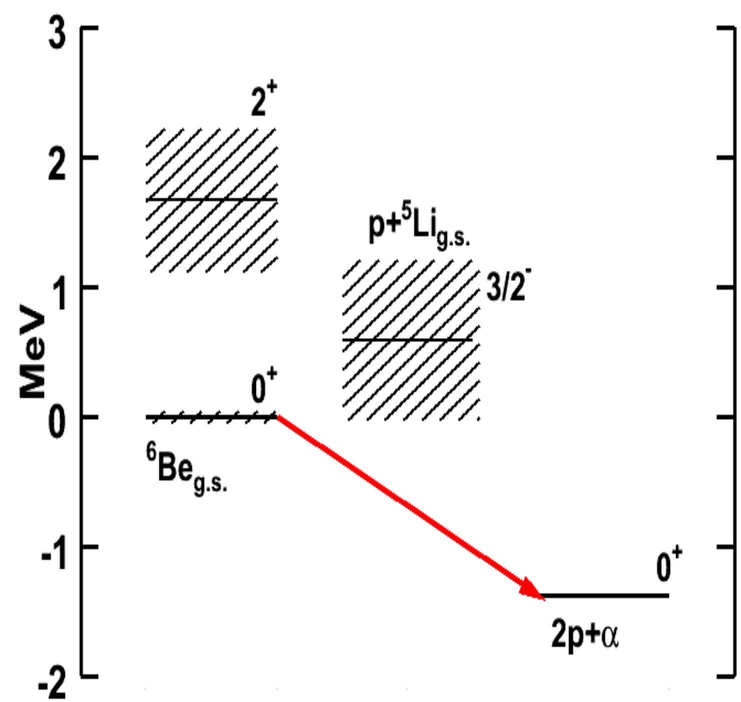


Goldansky, even Z (pairing) (^{45}Fe, ^{48}Ni)
Prompt 2*p* decay



Democratic , wide intermediate state
Lifetime too short and so must
treat as prompt 2*p* decay.
Again pairing can be important (even Z)

2*p* decay of light ground-state nuclei can be a combination of Goldansky and Democratic
e.g. ^6Be



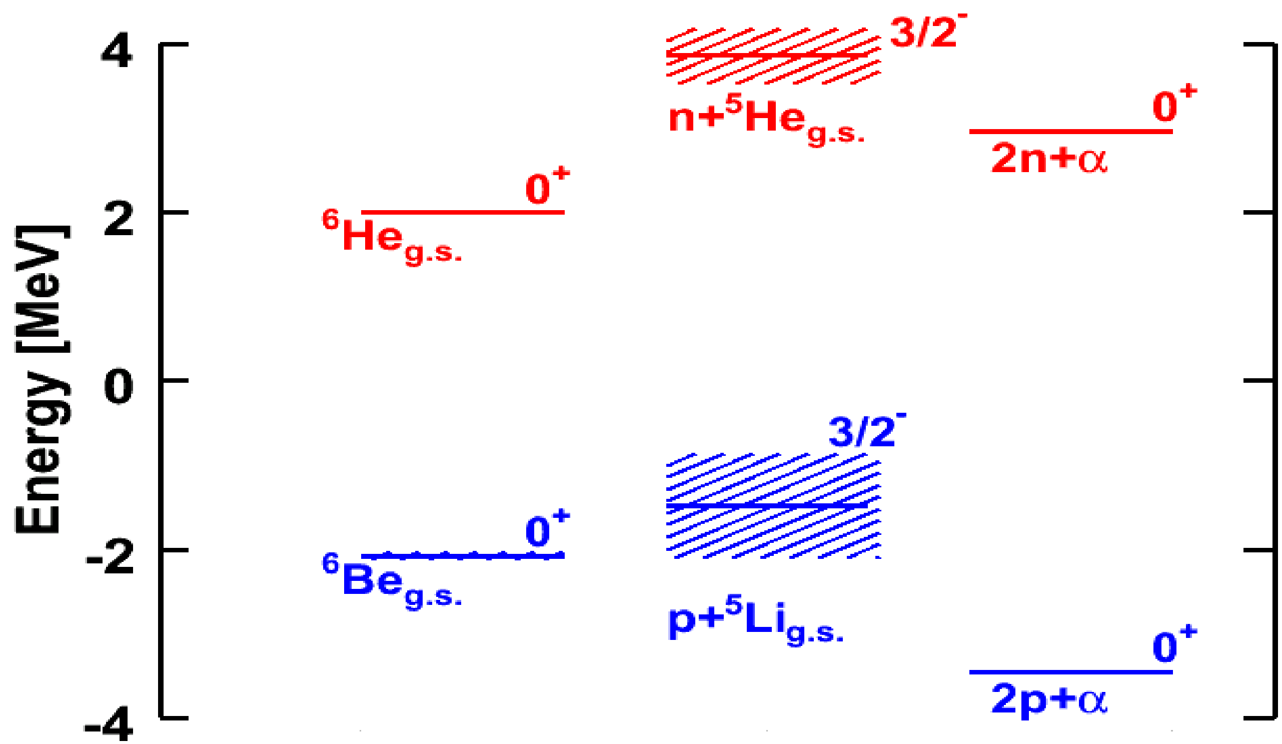
Relationship between 2p-decay and 2n-halo nuclei

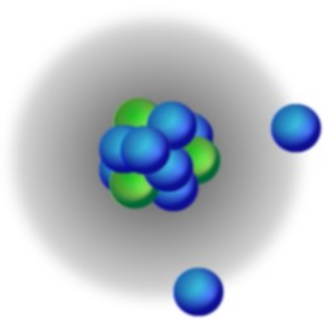
Mirror pairs
^{6}He – ^{6}Be

^{8}He – ^{8}C

^{11}Li – ^{11}O?

2n-halo
Borromean nuclei - removing one element make the entire structure unstable



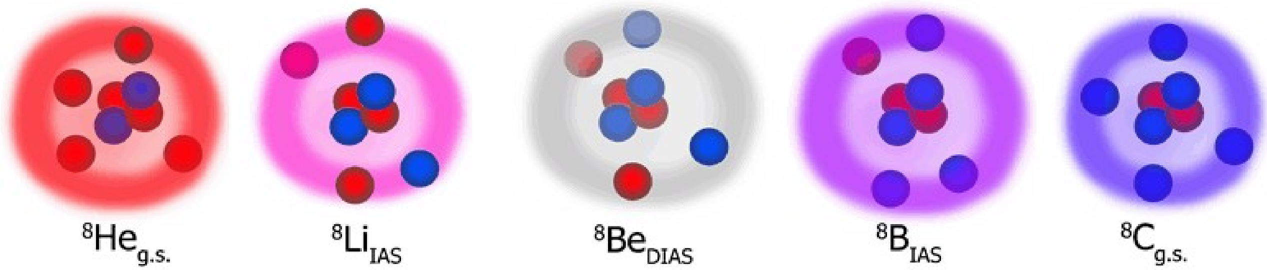


Difference between ^{6}Be and ^{6}He is the Coulomb energy. ^{6}Be = leaky 2p-halo nucleus.

4n- halo

mixed 2n+2p halo

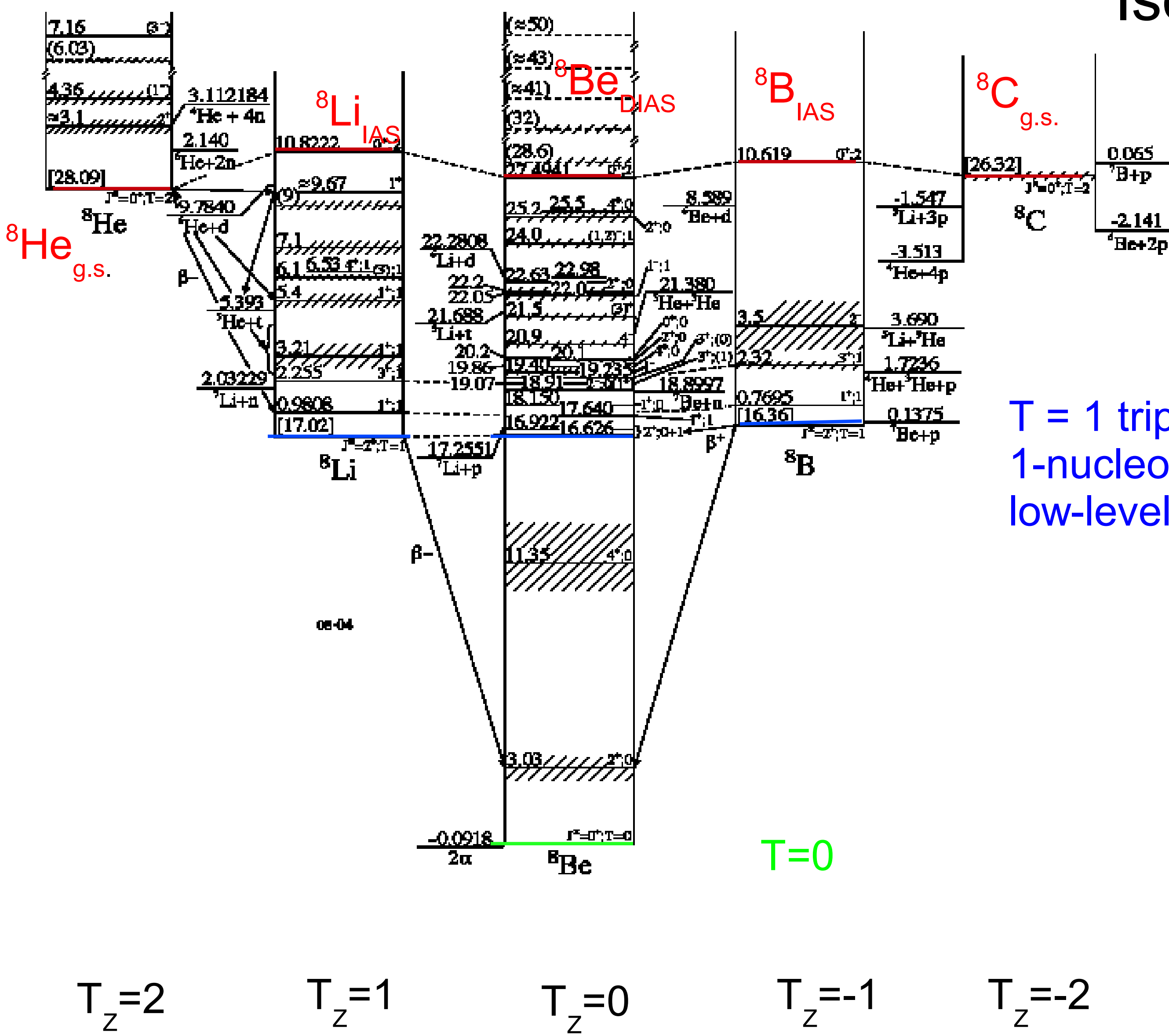
Leaky 4p-halo



Halo structure of T=2 quintet

α core + 4-nucleon halo

Isobaric multiplets for A=8



T = 2 quintet (2T+1)

4-nucleon halo

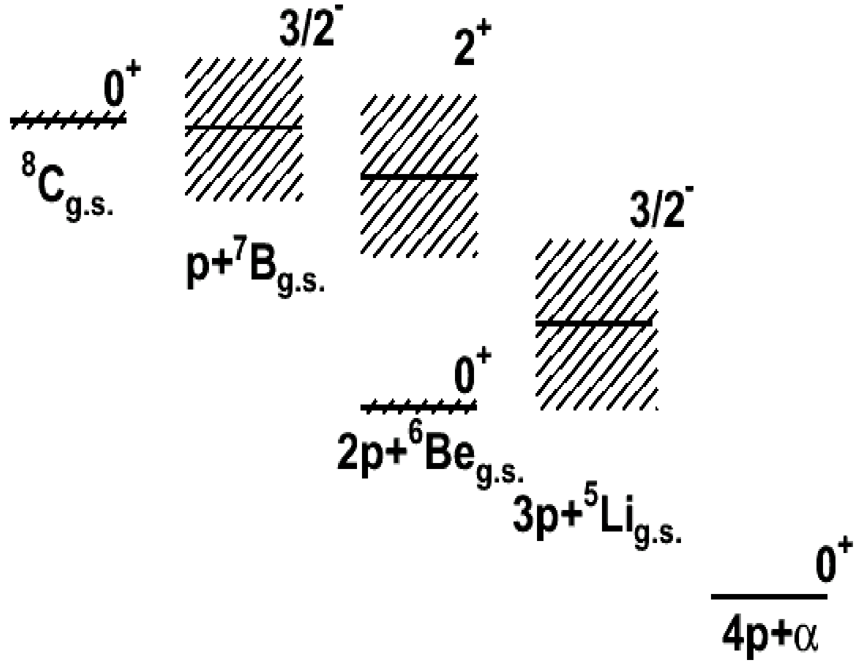
high-level bridge

T = 1 triplet

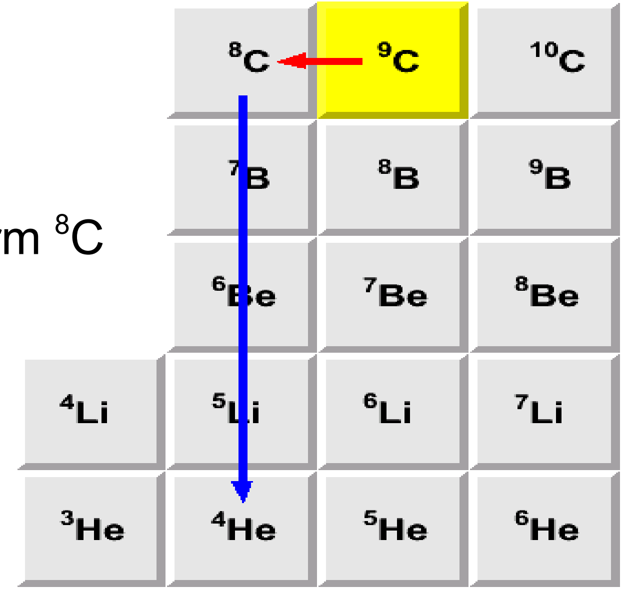
1-nucleon halo

low-level bridge

Exotic briges

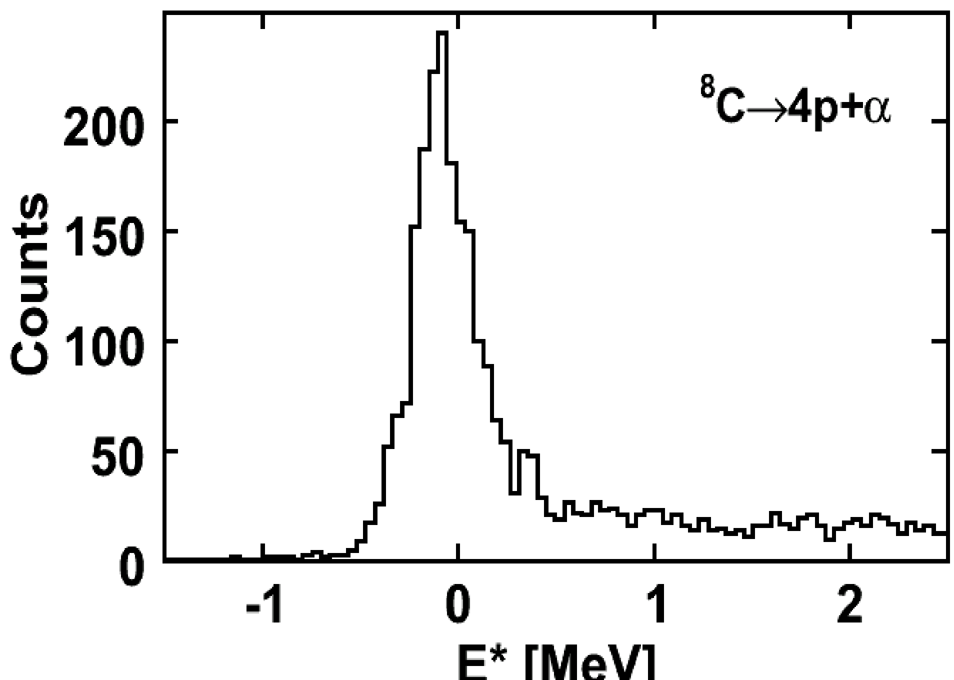


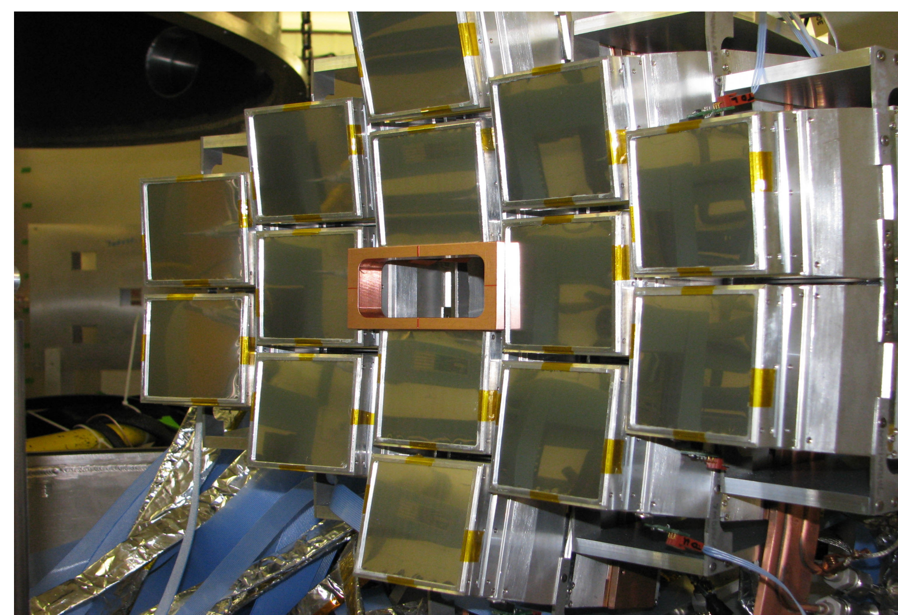
E/A=70 MeV ^{9}C
^{9}Be target
HiRA array
n-knockout to form ^{8}C

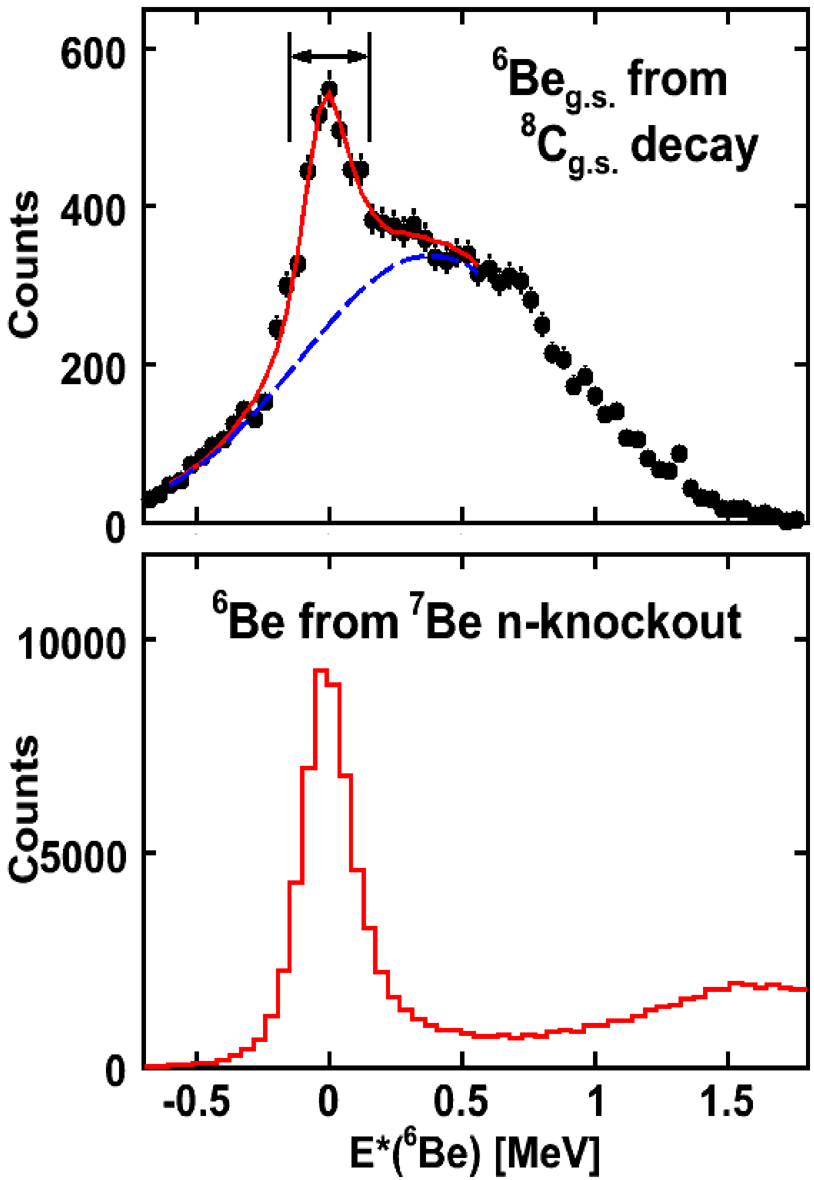


Five-body decay?
Some type of sequential decay?
Only long-lived intermediate possible is ^{6}Be$_{g.s.}$
~2000 events detected
~2% efficiency
New measurement of mass excess and width.

PRC 84 (2011) 014320







Looking for ^{6}Be in ^{8}C decay.

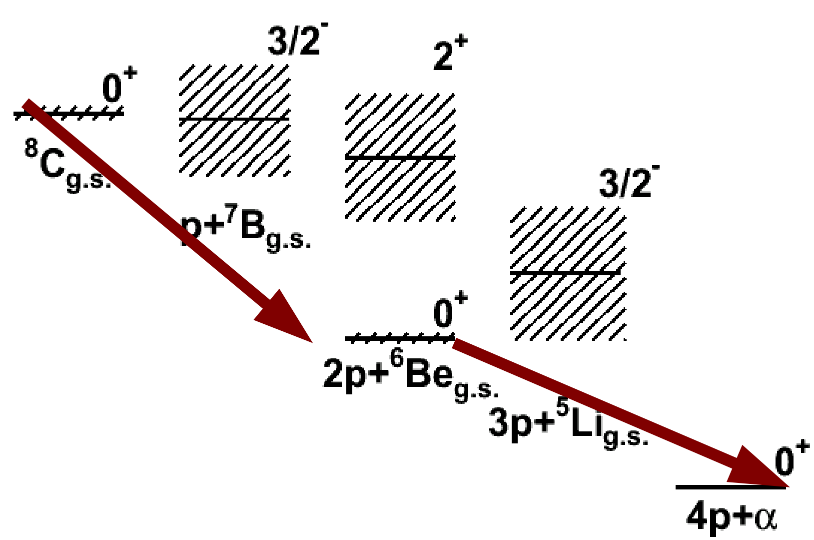
$^6Be \rightarrow 2p+\alpha$

Six possible $2p+\alpha$ subsets in each detected $4p+\alpha$ event. Histogram ^{6}Be excitation energy for each of these ways.

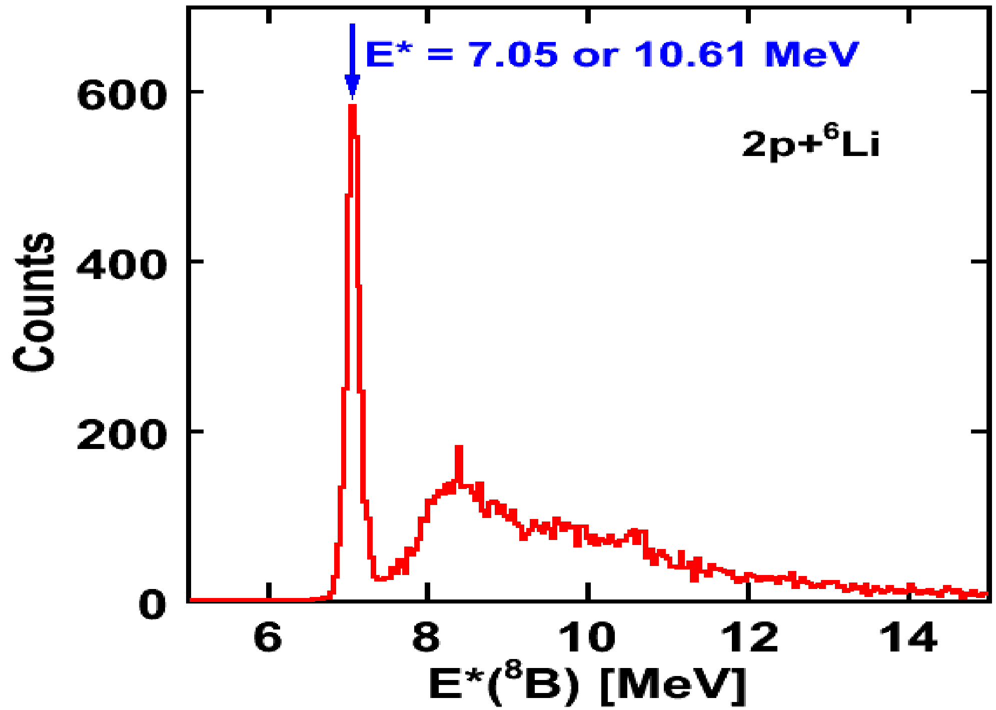
Fit $^6Be_{g.s.}$ peak → 1.01±0.05 $^6Be_{g.s.}$ fragments in each $^8C_{g.s.}$ event.

All $^8C_{g.s.}$ Fragments decay through $^6Be_{g.s.}$

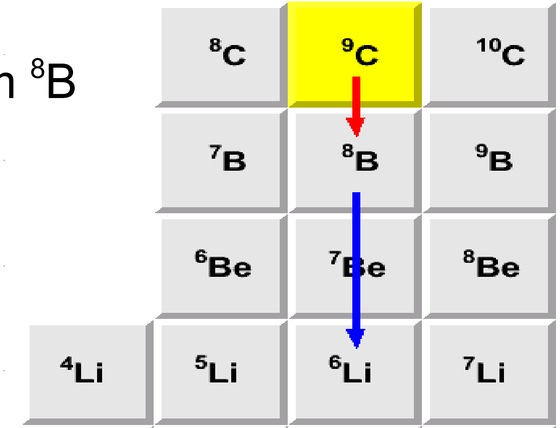
Two sequential steps of 3-body decay.



PRC 84 (2011) 014320



p-knockout to form ^{8}B



^{8}B excited state → 2p + ^{6}Li
Measured E* = 7.05 or 10.61 MeV Γ < 75 keV

No known narrow level at 7.05 MeV

$^8B_{IAS}$ E*=10.619±0.009 MeV, Γ<60 keV

2p decay from IAS to IAS

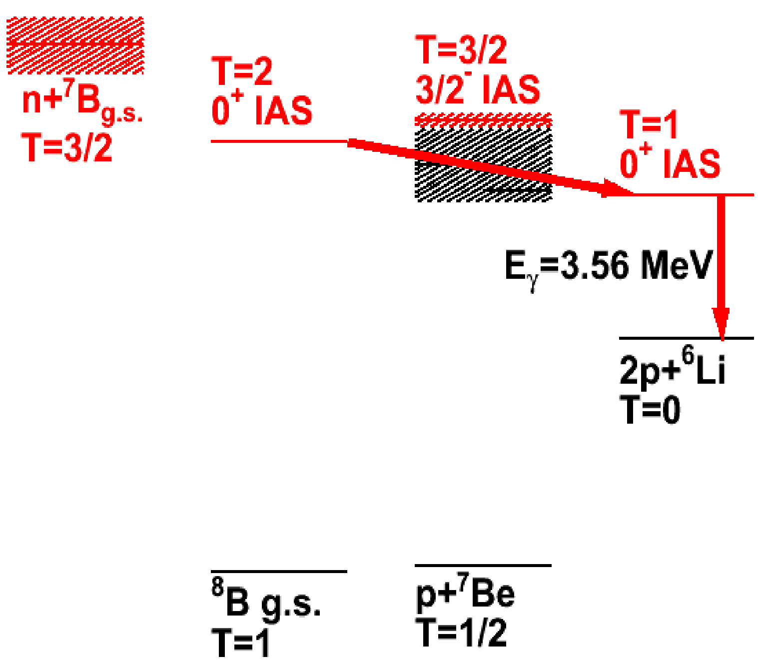
$^8B_{IAS} \rightarrow 2p + {}^6Li_{IAS}$

Analog sates

$^8C_{g.s.} \rightarrow 2p + {}^6Be_{g.s.}$

The two proton decay of $^8B_{IAS}$ is the only isospin-allowed decay mode possible.

To the extent that isospin is conserved, this is a Goldansky-type 2p decay.



Isobaric Multiplet Mass Equation

If no Coulomb and isospin is a good quantum Number, then mass of neutron = mass of proton. All members of an isobaric multiplet would have the same mass.

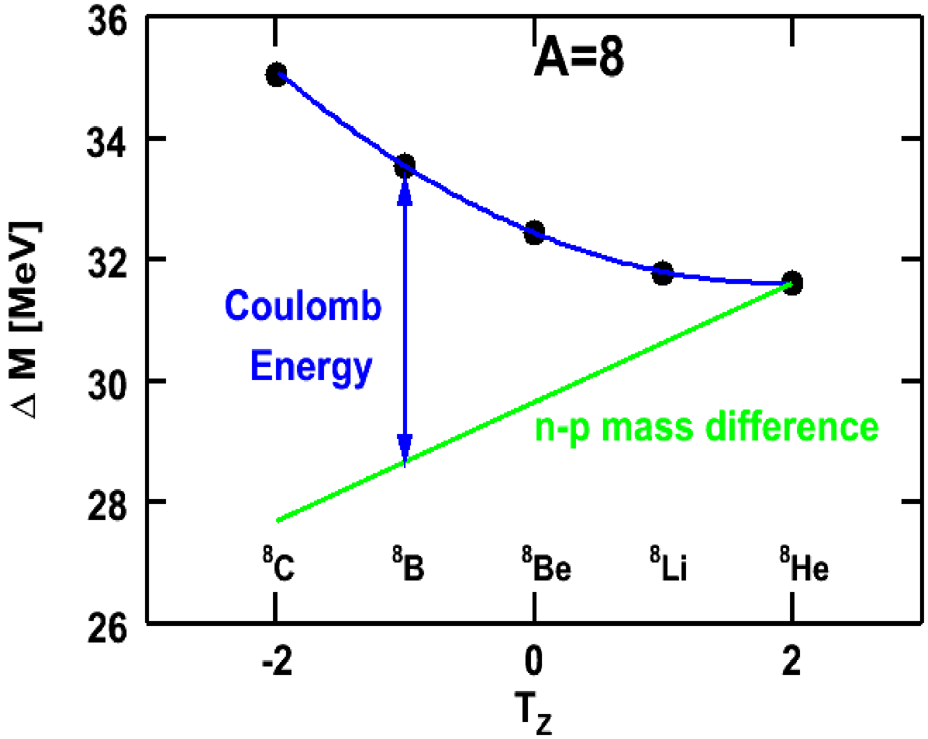
Differences in masses comes mainly from *n-p* mass difference and the Coulomb energy. Wigner showed that for a multiplet with isospin T, the mass is

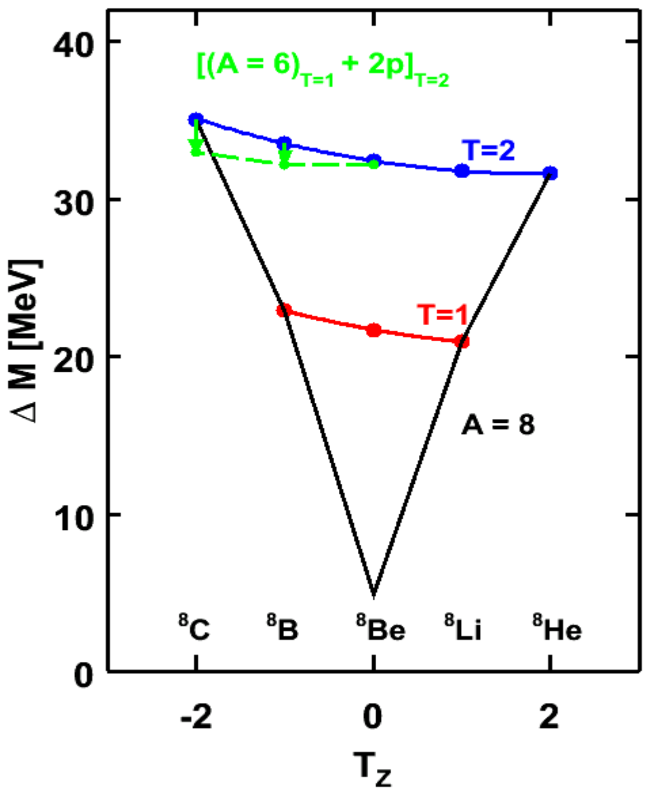
$$M(T,T_z) = a + b\,T_z + c\,T_z^2$$

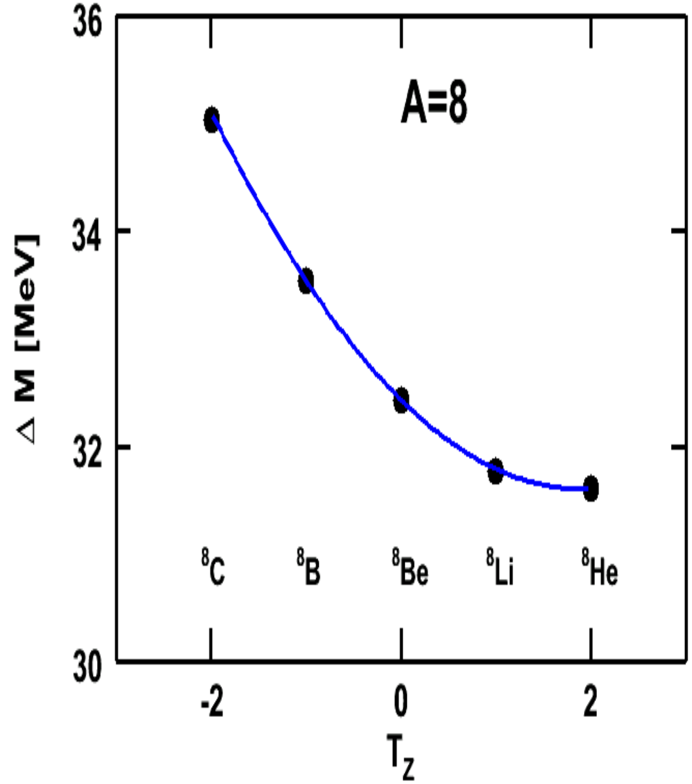
$T_z = (N-Z)/2$ = isospin projection

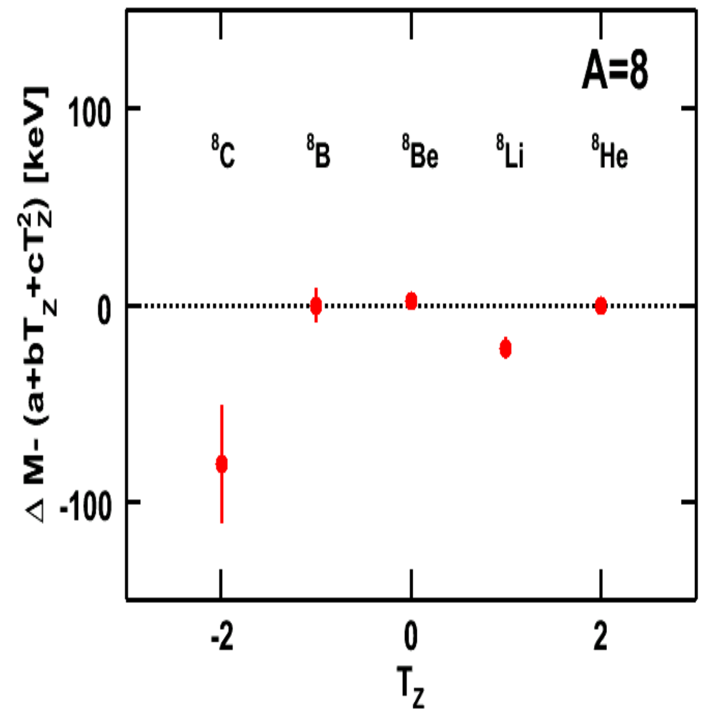
Deviations to this would be related to non-isospin conserving nuclear forces.

The IMME works quite well, with only a few exceptions.





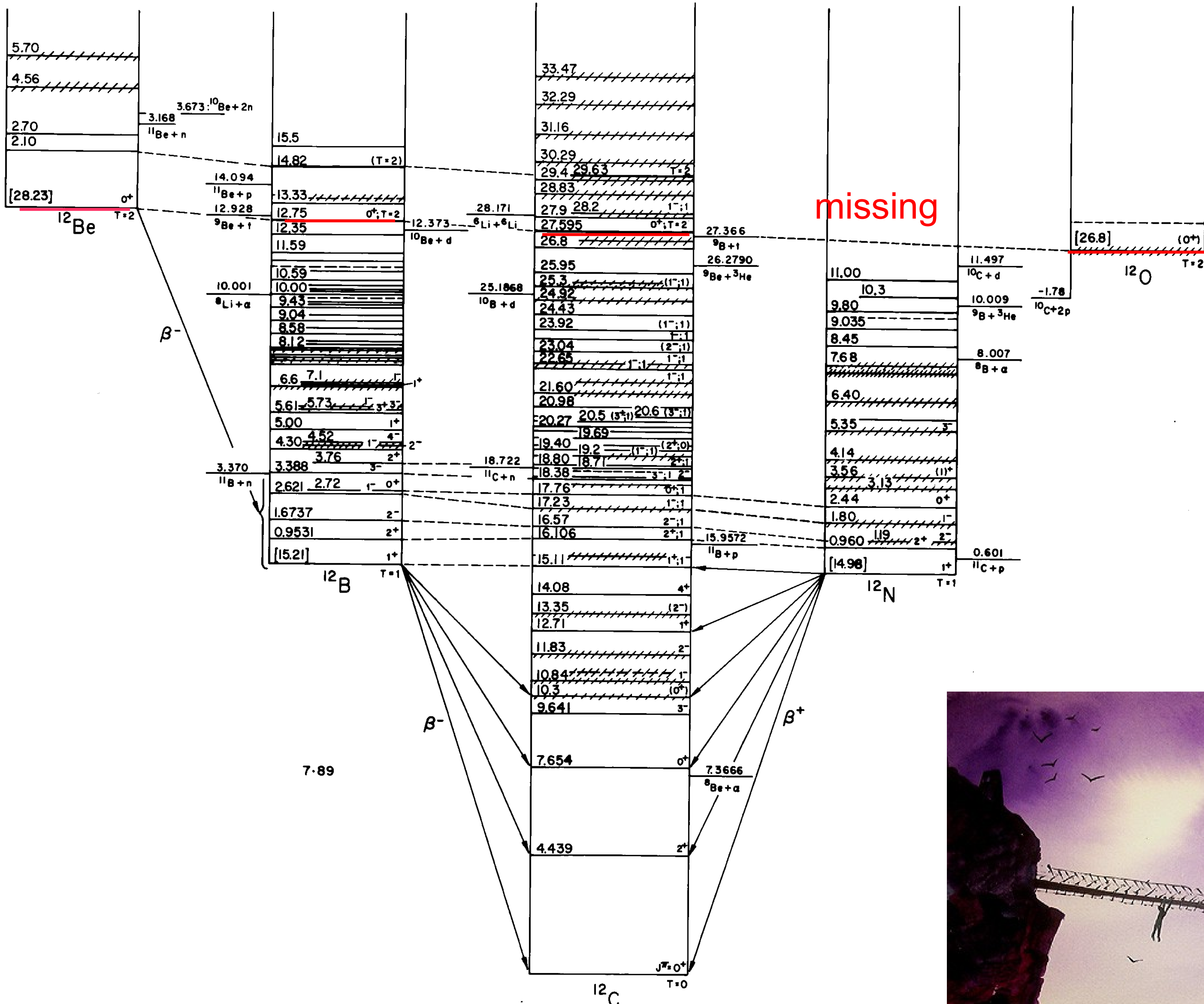


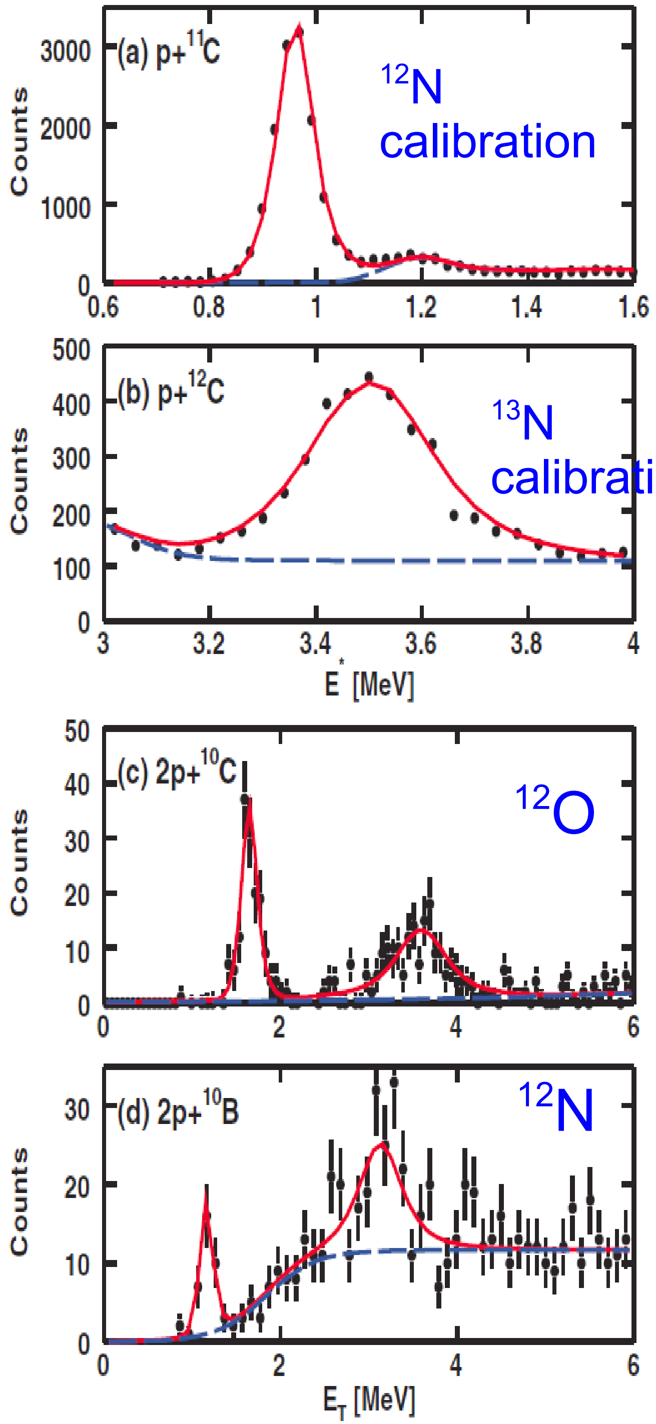


The quadratic IMME equation work well, but deviations of the order of 100 keV were found. This is the largest deviation found for any isobaric multiplet. Isospin Violation. Smaller violations also found for A=7,9 quartets.
The effect is not fully understood at present.

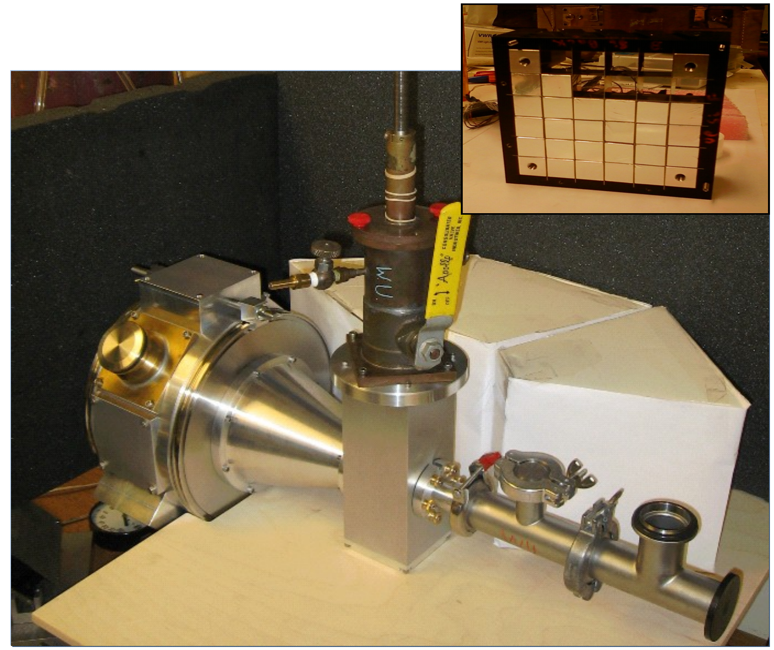
PRC 84 (2011) 051308R

Bridges with missing pieces



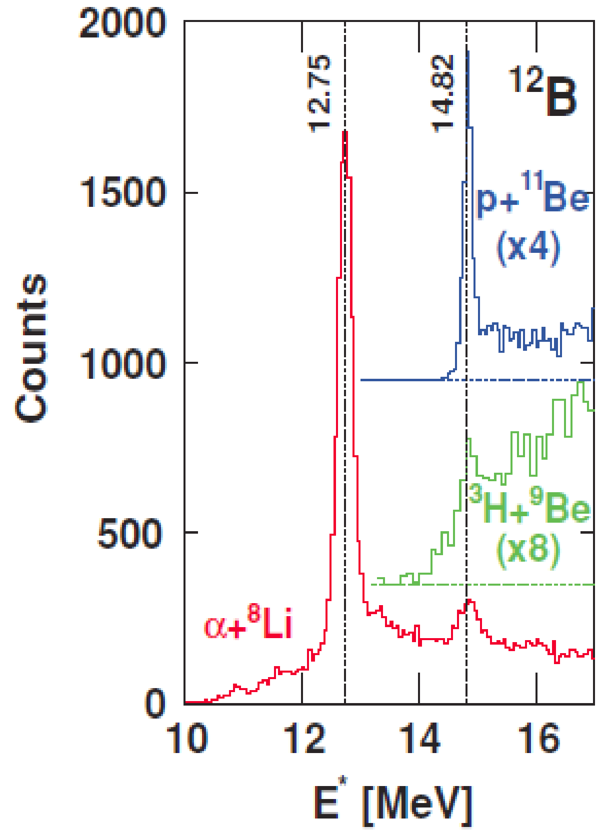


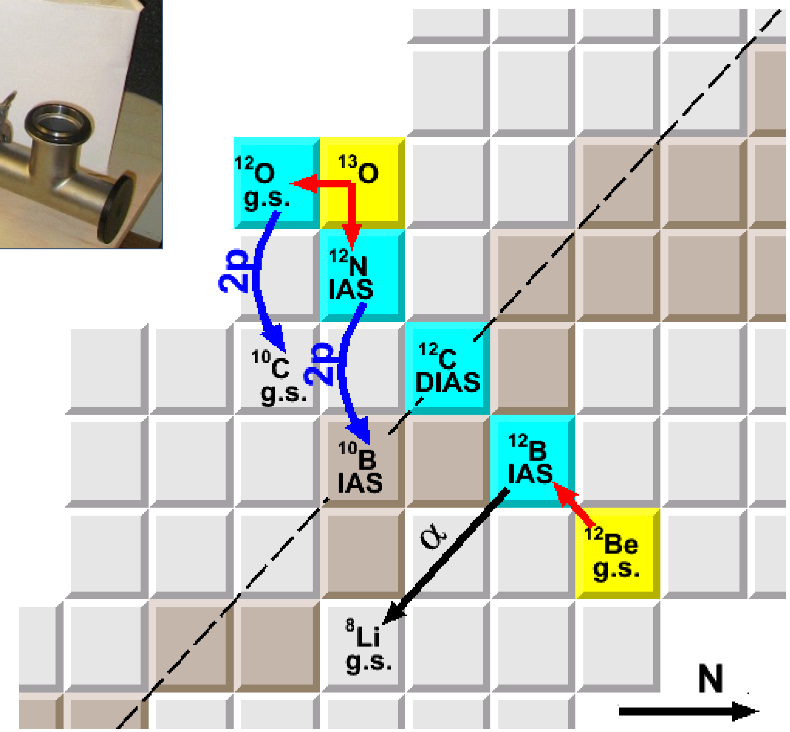
PRC 86 (2012) 011304R



E/A=30 MeV ^{13}O beam
Texas A&M university
^{9}Be target

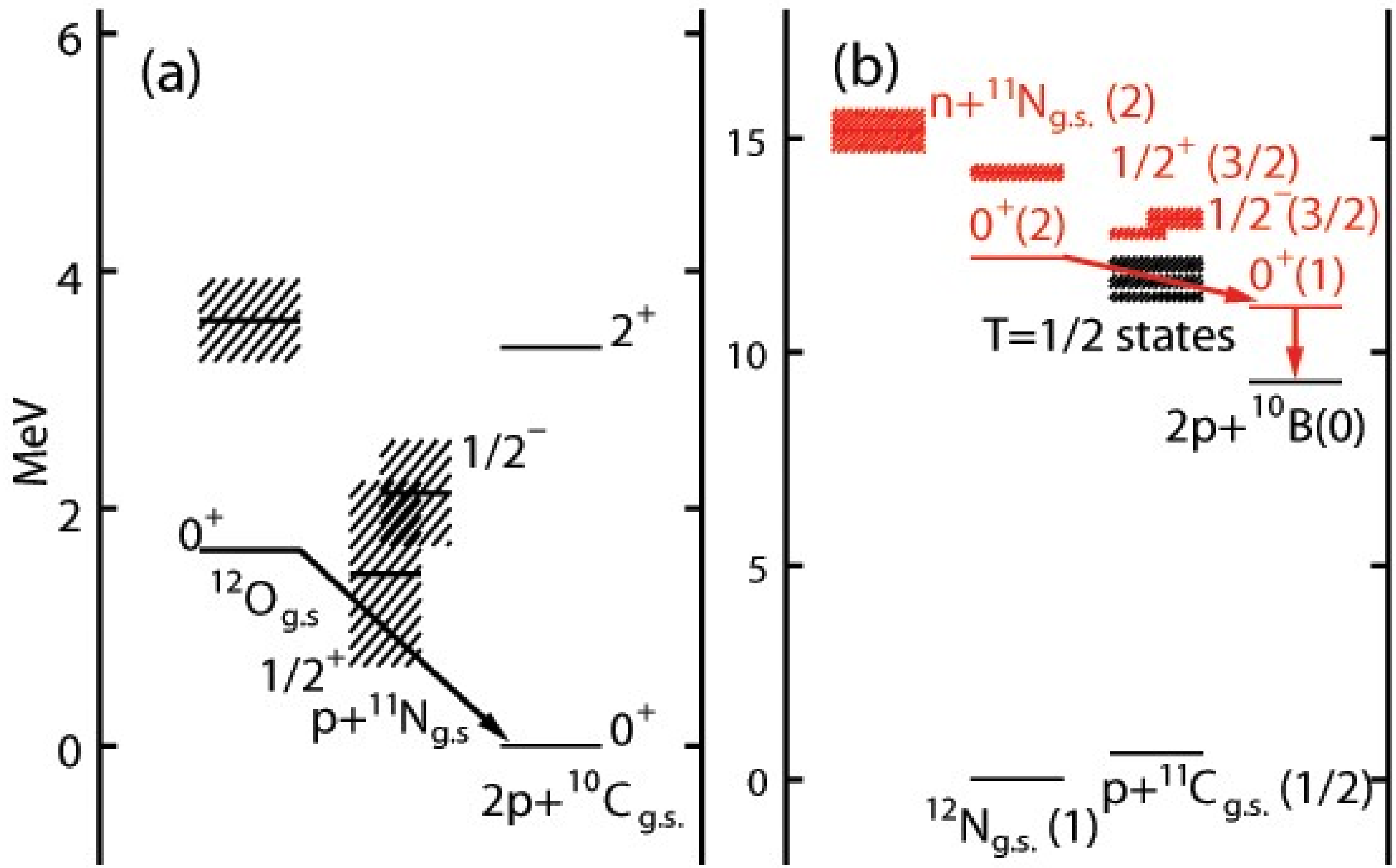
Neutron knockout → ^{12}O
Proton knockout → ^{12}N





E/A=50 MeV ^{12}Be
HiRA@NSCL
Polyethylene target
^{12}Be(*p*,*n*)^{12}B

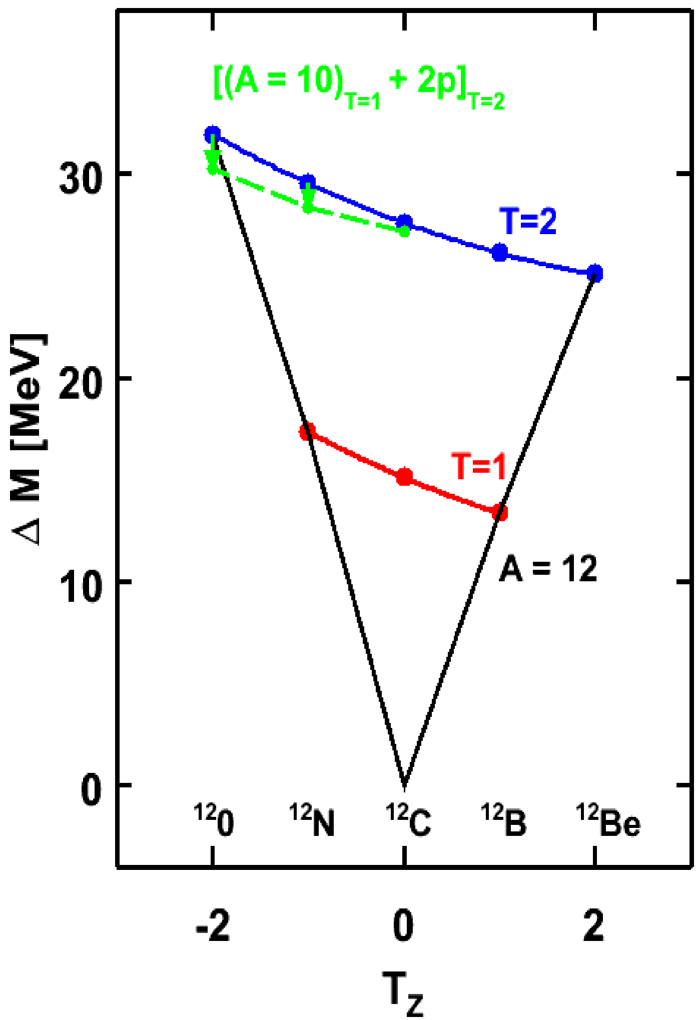
PRC 78 (2008) 054307

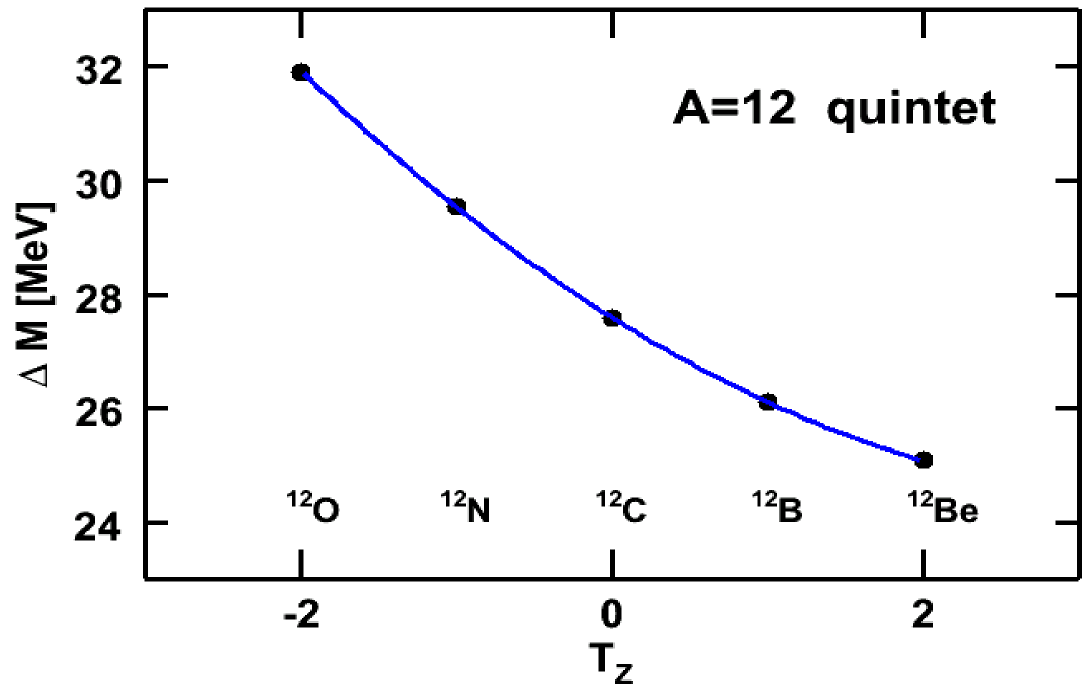


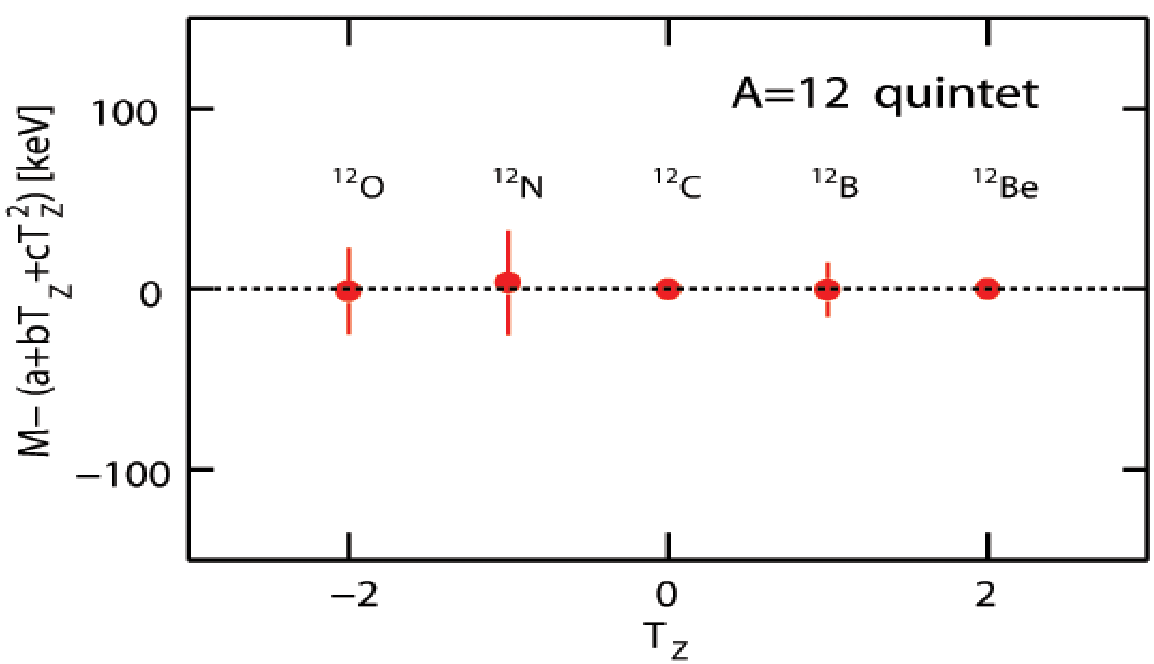
Democratic *2p*-decay

Goldansky *2p*-decay to the extent that isospin is conserved, similar to The 2p-decay of $^{8}B_{IAS}$

IMME for A=12 quintet $M(T,T_z) = a + b\,T_z + c\,T_z^{\,2}$







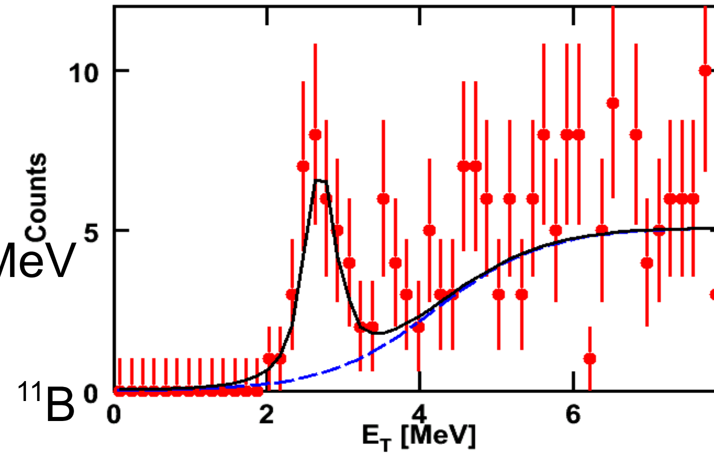
No Deviations from quadratic fit.
No isospin violation

PRC 86 (2012) 011304R

A=11 Sextet T=5/2, J=3/2$^-$

Unfinished Bridge

^{11}B → 2p+^{9}Li (decay branch)



E*=33.6 MeV
Γ=306(182) keV

^{12}Be(p,2n)^{11}B reaction at E/A = 50 MeV
@NSCL with HiRA array.

double isobaric analog state in ^{11}B

Isobaric analog state
known (RIKEN 1997)
p+n decay

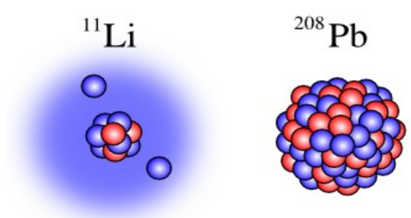
Known
particle-stable

Isospin-allowed 2*p* decay possible

^{11}O

T=5/2, J=3/2$^-$, sextet
two-nucleon halo

^{11}Li



^{11}N

T=3/2, J=1/2$^+$,quartet
one-nucleon halo

^{11}Be

^{11}C

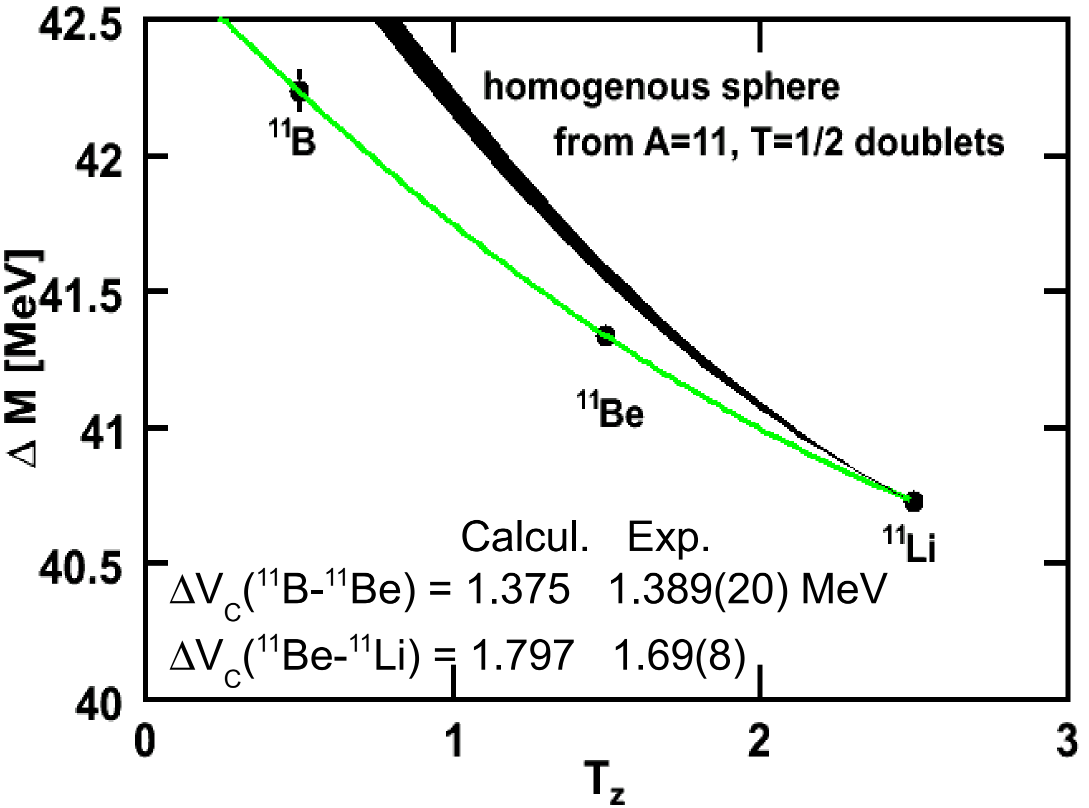
^{11}B

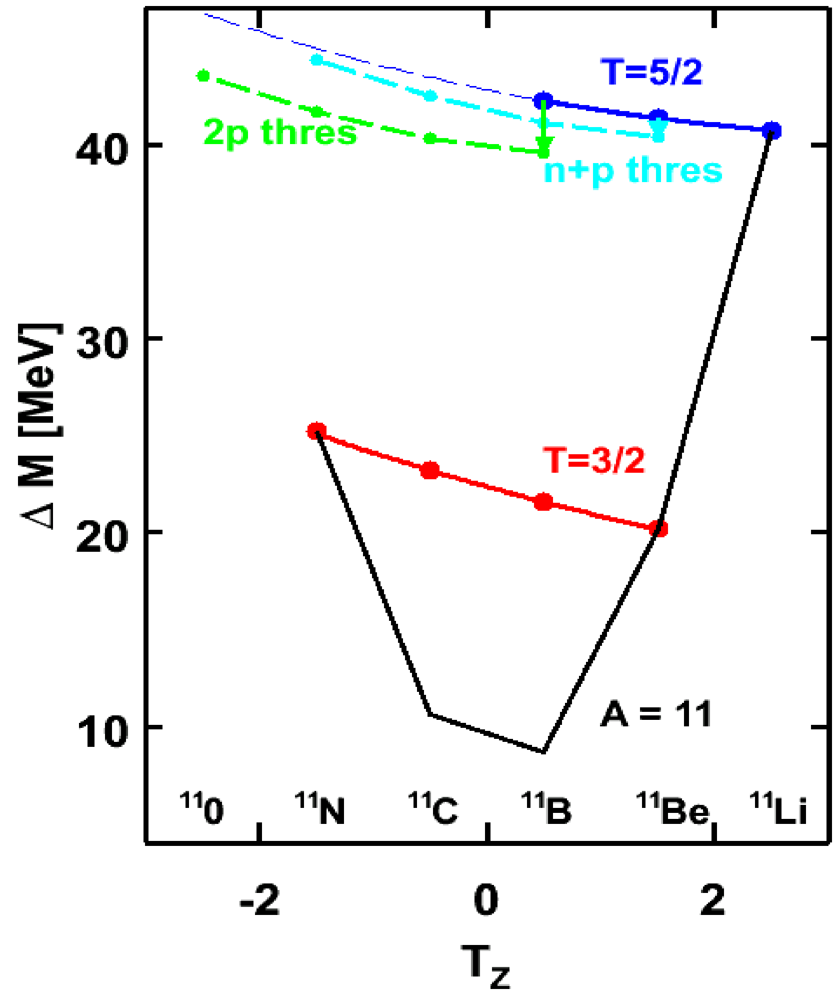
T=1/2, J=3/2$^-$, doublet

Isobaric Multiplet Mass Equation for A=11, T=5/2

Masses show the effect of the extended halo.
Consistent with ^{11}Li halo wavefunctions calculated by Hagino + Sagawa PRC **72** (2005) 044321

Can extrapolate to masses of proton-rich members of the sextet.





Summary

Exotic structure in light nuclei is not confined to nuclei near the drip lines (high T_z) but more generally to states with high T.

Strong connection between two-proton decay and two-neutron halo nuclei.

Two-proton decay of proton rich members of the
A=6, T=1 triplet ^{6}Be -^{6}Li- ^{6}He
A=8, T=2 quintet ^{8}C-^{8}B-^{8}Be-^{8}Li-^{8}He
A=11, T=5/2 sextet ^{11}O-^{11}N-^{11}C-^{11}B-^{11}Be-^{11}Li
A=12. T=2 quintet ^{12}O-^{12}N-^{12}C-^{12}B-^{12}Be

Isobaric multiplet mass equation is sensitive to the halo structure of the A=11 sextet consistent with calculations of Hagino and Sagawa